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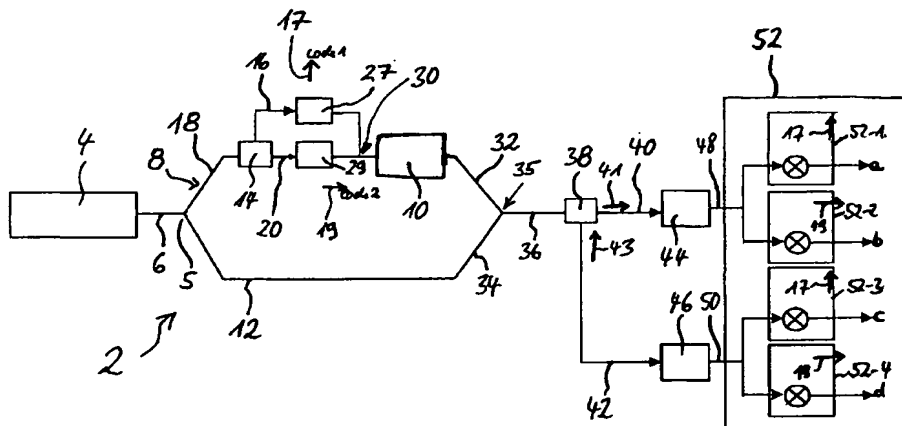
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(54) Title: CODED POLARIZATION-DEPENDENT ANALYZING



(57) Abstract: The present invention relates to an apparatus and to a method of polarization dependent analyzing an optical signal (6) transmitted through a DUT (10), comprising the steps of: splitting the optical signal (6) into a first signal part (16) having an initial first polarization and a second signal part (20) having an initial second polarization, coding the first signal part (16) using a first code (17, code 1) and coding the second signal part (20) using a second code (17, code 2), providing the coded signal parts (16, 6a, 20, 6b, 6c, 6d) to the DUT (10), detecting a DUT signal (32) coming from the DUT (10) in response to the coded signal parts (16, 6a, 20, 6b, 6c, 6d), and determining a first part (a, c) of the DUT signal (32) corresponding to the first signal part (16) by means of the first code (17, code 1) and determining a second part (b, d) of the DUT signal (32) corresponding to the second signal part (20) by means of the second code (17, code 2).

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CODED POLARIZATION-DEPENDENT ANALYZING

BACKGROUND OF THE INVENTION

The present invention relates to analyzing an optical signal transmitted through a device under test (DUT), in particular to analyzing an optical signal transmitted through a DUT located in a measurement arm of an interferometric measurement setup.

SUMMARY OF THE INVENTION

It is an object of the invention to provide improved analyzing an optical signal transmitted through a DUT. The object is solved by the independent claims.

When analyzing an optical signal transmitted through a DUT it can be advantageous to resolve polarization dependent information about polarization dependent properties of the DUT. Although this information is contained in the resulting signal, so far it requires repeated measurements to allocate this information to certain polarizations since there is only one signal leaving the DUT. An advantage of an embodiment of the present invention is the possibility of polarization dependent analyzing such an optical signal coming from the DUT.

Although signal parts having a certain polarization are superimposed it is possible to unambiguously separate the information in each signal part allocated to a certain polarization due to the present invention. This is made possible by making each signal part unique. Preferably, this can be done by coding each signal part. According to the present invention coding can be any type of coding as long as it is possible to identify each signal part by the used way of coding. E.g. coding could be done by any unambiguous coding scheme as known in the art, such as e.g. by modulating the signal (preferably with a pilot tone at a special frequency), and/or by applying a special code to the signal, etc.

For the purposes of the present invention it is not necessary to provide each signal with a coding, i.e. it is possible to let at least one of the signals uncoded.

The signals are preferably coded by intensity modulation of the signals, more preferably by using sinusoidal signals or binary codes.

The demodulation of the signal can be done by multiplying the signal with a corresponding sinusoidal signal of dedicated frequency or by multiplying the signal with each code. Due to the preferred orthogonality of the frequencies / codes it is then possible to allocate the thereby resolved information to a certain polarization.

- 5 In a first embodiment of the present invention the light emitted from a light source is split into at least two different light paths. Light in each arm is now coded. Afterwards the light is sent through at least two polarizers. Thus each polarization gets assigned a unique pilot tone frequency or code. At the output of the polarizer the light is combined again and sent through the DUT. A photo detector detects light leaving the DUT.
- 10 It is preferred and advantageous to modulate the light by orthogonal signals. For the case of using a pilot tone it is sufficient to modulate the signal by at least two different pilot frequencies. By using codes the codes are preferably orthogonal codes. This is preferred to resolve the information contained in the resulting signal and to avoid interference between the coded parts.
- 15 Due to the preferred embodiment of the invention it is possible to measure at least two polarizations simultaneously.

- In a second embodiment of the present invention the DUT is located in a measurement arm of an interferometric measurement setup. It is possible to perform such interferometric measurements with an optical signal tuned in frequency or wavelength
- 20 provided by a tunable laser source (TLS). Due to a preferred embodiment of the invention it is possible to make single sweep measurements in such setups and still gaining the polarization dependent information about the DUT.

- Possible application fields of embodiments of the present invention are all measurement setups for measuring an optical property of a device under test using a
- 25 TLS.

Other preferred embodiments are shown by the dependent claims.

It is clear that the invention can be partly embodied or supported by one or more suitable software programs, which can be stored on or otherwise provided by any kind of data carrier, and which might be executed in or by any suitable data processing unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and many of the attendant advantages of the present invention will be readily appreciated and become better understood by reference to the following detailed description when considering in connection with the accompanied drawings.

- 5 The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Features that are substantially or functionally equal or similar will be referred to with the same reference sign(s).

Fig. 1, 2 and 3 show schematic illustrations of embodiments of the present invention.

10 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE
INVENTION

- Referring now in greater detail to the drawings, Fig. 1 shows a schematic illustration of a first embodiment of the present invention. According to this embodiment an optical signal 6 of a TLS 4 is provided to a first coupler 105. The first coupler 105 has 4 output
15 ports and splits the optical signal 6 into 4 parts 6a, 6b, 6c and 6d. Each signal part 6a, 6b, 6c and 6d is modulated by modulators 27, 29, 127 and 129, respectively. The first signal 6a is modulated using a first binary code code 1, the second signal part is modulated using a second binary code code 2, the third signal part is modulated using a third binary code code 3, and the fourth signal part is modulated using a fourth binary
20 code code 4. Codes 1, 2, 3 and 4 are orthogonal to each other.

- Subsequently each coded signal 6a', 6b', 6c', 6d' receives a defined polarization by polarization controllers 27a, 29b, 127c, 129d in the path of the coded signal 6a', 6b', 6c', 6d', respectively. The resulting polarized signals 6a'', 6b'', 6c'', 6d'' are then combined at a coupler 135 and provided as a superimposed signal 136 to a DUT 10.
25 As modulators 27, 29, 127, 129 intensity modulators (e.g. LiNbO₃- based) can be used.

A signal 140 leaving the DUT 10 is then detected at a detector 44. A detector signal 48 containing coded signals for main polarizations and cross polarization is then provided to a correlation unit 52 containing four correlators 52-1, 52-2, 52-3 and 52-4. Each

correlator 52-1, 52-2, 52-3 and 52-4 is demodulating the signal 48 by multiplying signal 48 with the codes code 1, code 2, code 3 and code 4, respectively. The results of the demodulation is then provided by the correlation unit 52 at output ports a, b, c and d of the correlators 52-1, 52-2, 52-3 and 52-4, respectively.

5 Figure 2 shows a second embodiment of the present invention. It comprises an interferometer 2. Interferometer 2 comprises a TLS 4 providing an optical signal 6 to a first coupler 5 connected to a measurement arm 8, containing a DUT 10, and to a reference arm 12. Measurement arm 8 comprises a polarization beam splitter (PBS) 14 located before the DUT 10 splitting a measurement signal 18 into a first part 16 having
10 a first polarization and a second part 20 having a second polarization orthogonal to the first polarization. The first part 16 is modulated by a modulator 27 with a first binary code (code 1) indicated by an arrow 17 and the second part is modulated by a modulator 29 with a second binary code (code 2) indicated by an arrow 19. Then at coupler 30 both parts are combined and provided to the DUT 10. As modulators 27, 29
15 intensity modulators (e.g. LiNbO₃-based) are used here.

A signal 32 leaving the DUT 10 is then superimposed at a coupler 35 with a reference signal 34 of reference arm 12 to a superimposed signal 36. Subsequently the superimposed signal 36 is orthogonal split by a second PBS 38 into two orthogonal parts 40 and 42, the polarization of which is indicated by arrows 41 and 43,
20 respectively. Parts 40 and 42 are provided to detectors 44 and 46. The signals 40 and 42 at each detector 44 and 46 contain both the information about the first polarization, e.g. the main polarization, and the second polarization, e.g. the cross polarization. The detector signals 48 and 50 are provided to a correlation unit 52 containing four correlators 52-1, 52-2, 52-3, and 52-4. Each correlator 52-1, 52-2, 52-3, and 52-4 is
25 demodulating the signals 48 and 50, respectively, by multiplying each signal with the respective codes 17 or 19 as indicated by the circles containing crosses in Fig. 1. The result of the demodulation is then provided at output ports a-d of the correlators 52-1 to 52-4.

Fig. 3 shows a schematic illustration of another embodiment of the present invention.
30 According to this embodiment, the reference arm 12 contains a delay line 60 providing a delay $\Delta\tau$ to the reference signal 34. For further details of the construction and the

function of the delay line 60, it is referred to the parallel International patent application No. PCT/EP02/07726 of the applicant, the disclosure of which is incorporated herein by reference.

Furthermore, after the delay line 60, there is integrated in the reference arm 12 a third
5 modulator 62, which is prepared to apply a reference code (code ref) to the reference signal 34. Contrary to the embodiment of Fig. 1, there is provided a coupler 64 to split the resulting superimposed signal 36 into a first part 36a and a second part 36b before being split by PBS 38. The second part 36b is then provided to a third detector 66 that provides a signal 68 to a fifth correlator 70. Correlator 70 identifies a part of the
10 superimposed resulting signal 36 corresponding to the reference signal 34 by multiplying the second part 36b of the reference signal 36 with the reference code ref. In order to separate the signals it is required that code 1 and code 2 are orthogonal and code 1 and code ref are non-orthogonal and code 2 and code ref are also non-orthogonal.

15 Since delay line 60 provides a periodic delay $\Delta\tau$ to the reference signal 34, it is possible to analyze DUTs 10 with large delays.

The result of the interferometric analysis according to the embodiments illustrated in Figs. 2 and 3 is provided for each state of polarization provided by PBS 14 at outputs a-d of the respective correlators 52-1 to 52-4. Accordingly, a wavelength reference
20 signal is unambiguously provided at output e of correlator 70.

CLAIMS:

1. A method of polarization dependent analyzing an optical signal (6) provided to a DUT (10), comprising the steps of:

5 splitting the optical signal (6) at least into a first signal part (16, 6a) having an initial first polarization and a second signal part (20, 6b) having an initial second polarization,

 coding the first signal part (16, 6a) using a first code (17, code 1) and coding the second signal part (20, 6b) using a second code (19, code 2),

 providing the coded signal parts (16, 6a, 20, 6b) to the DUT (10),

10 detecting a DUT-signal (32, 140) coming from the DUT (10) in response to the coded signal parts (16, 6a, 20, 6b), and

 determining a first part (a, c) of the DUT-signal (32) corresponding to the first signal part (16, 6a) by means of the first code (17, code 1) and determining a second part (b, d) of the DUT-signal (32, 140) corresponding to the second signal
15 part (20, 6b) by means of the second code (19, code 2).

2. The method of claim 1, further comprising the steps of:

 additionally splitting the optical signal (6) into a third signal part (6c) having an initial third polarization and a fourth signal part (6d) having an initial fourth polarization,

20 coding the third signal part (6c) using a third code (code 3) and coding the fourth signal part (6d) using a fourth code (code 4),

 providing the first (16, 6a), the second (20, 6b), the third (6c) and the fourth coded signal parts (6d) to the DUT (10),

 detecting a DUT signal (32, 140) coming from the DUT (10) in response to the
25 coded signal parts (16, 6a, 20, 6b, 6c, 6d)) and

 determining a first part (a, c) of the DUT-signal (32, 140) corresponding to the first

5 signal part (16, 6a) by means of the first code (17, code 1) and determining a second part (b, d) of the DUT-signal (32, 140) corresponding to the second signal (20, 6b) by means of the second code (19, code 2) and determining a third part (c) of the DUT-signal (32, 140) corresponding to the third signal part (6c) by means of the third code (code 3) and determining a fourth part (d) of the DUT-signal (32, 140) corresponding to the fourth signal part (6d) by means of the fourth code (code 4).

3. The method of claim 1 or any one of the above claims, wherein coding comprises at least one of a group comprising:

10 any manipulation of the signal parts (16, 6a, 20, 6b, 6c, 6d) to unambiguously identify each signal part (16, 6a, 20, 6b, 6c, 6d),

intensity modulating at least one of the signal parts (16, 6a, 20, 6b, 6c, 6d),

using a binary code for at least one of the signal parts (16, 6a, 20, 6b, 6c, 6d).

4. The method of claims 1 or any one of the above claims,

15 wherein at least one of the applied polarizations (first, second, third, and forth polarizations) is orthogonal with respect to each of the other polarizations.

5. The method of claim 1 or any one of the above claims,

wherein at least one of the applied codes (17, code 1, code 2, code 3, code 4) is orthogonal with respect to each of the other codes.

20 6. The method of claim 1 or any one of the above claims, further comprising the steps of:

determining the parts (a, b, c, d) of the DUT-signal (32) by multiplying the DUT-signal (32) with each code.

25 7. The method of claim 1 or any one of the above claims, further comprising the steps of:

using the optical signal (6) as a measurement signal (18) of an interferometer

(30), and

superimposing the DUT-signal (32) coming from the DUT (10) with a reference signal (34) of the interferometer (30) before detecting the DUT-signal (32) to provide a resulting superimposed signal (36).

- 5 8. The method of claim 7, further comprising the steps of:

splitting the resulting superimposed signal (36) into two, preferably orthogonal, parts (40, 42) and detecting each part (40, 42) separately.

9. The method of claim 7 or any one of the above claims, further comprising the steps of:

- 10 providing the reference signal (34) with a delay (Δt) and with a reference code (ref), and

identifying the reference signal (34) by multiplying the reference signal (34) with the reference code (ref).

10. The method of claim 9, wherein the reference code (code ref) fulfils the following conditions: the product of the reference code (ref) with the first code (17, code 1) is orthogonal with the product of the reference code (code ref) with the second code (17, code 2), the first code (17, code 1) and the reference code (code ref) are non-orthogonal and the second code (17, code 2) and the reference code (code ref) are non-orthogonal, and

- 20 11. An apparatus for polarization dependent analyzing an optical signal (6) transmitted through a DUT (10), comprising:

a first beam splitter (14, 105) splitting the optical signal (6) into a first signal part (16, 6a) having an initial first polarization and a second signal part (20, 6b) having an initial second polarization,

- 25 a first modulator (27) coding the first signal part (16, 6a) using a first code (17, code 1),

a second modulator (29) coding the second signal part (20, 6b) using a second

code (17, code 2),

a coupler (35, 135) connected to the modulators (27, 29) reuniting both coded signal parts (16, 6a, 20, 6b, 6c, 6d) and providing both coded signal parts (16, 6a, 20, 6b, 6c, 6d) to the DUT (10),

5 a detector (44, 46) detecting a DUT-signal (32, 140) coming from the DUT (10) in response to the coded signal parts (16, 6a, 20, 6b, 6c, 6d),

a first correlator (52-1, 52-3) determining a first signal part (a, c) of the DUT-signal (32, 140) corresponding to the first signal part (16, 6a) by means of the first code (17, code 1), and

10 a second correlator (52-2, 52-4) determining a second part (b, d) of the DUT-signal (32, 140) corresponding to the second signal part (20, 6b) by means of the second code (17, code 2).

12. The apparatus of claim 11,

15 wherein the first beam splitter (14, 105) is designed to additionally split the optical signal (6) into a third signal part (6c) having an initial third polarization and a fourth signal part (6d) having an initial fourth polarization,

and further comprising:

a third modulator (127) coding the third signal part (6c) using a third code (code 3),

20 a fourth modulator (129) coding the fourth signal part (6d) using a fourth code (code 4),

wherein the coupler (35, 135) is additionally connected to the third (127) and the fourth modulator (129) and is designed to reunite the coded signal parts (16, 6a, 20, 6b, 6c, 6d) and to provide the first (16, 6a), the second (20, 6b), the third (6c) and the fourth coded signal parts (6d) to the DUT (10),

25 a third correlator (52-3) determining a third signal part (c) of the DUT-signal (32, 140) corresponding to the third signal part (6c) by means of the third code (code

3), and

a fourth correlator (52-4) determining a fourth part (d) of the DUT-signal (32, 140) corresponding to the fourth signal part (6d) by means of the fourth code (code 4).

13. The apparatus of claim 11 or any one of the above claims,

5 wherein coding comprises any manipulation of the signal parts (16, 6a, 20, 6b, 6c, 6d) to unambiguously identify each signal part (16, 6a, 20, 6b, 6c, 6d).

14. The method of claims 11 or any one of the above claims,

wherein at least one of the applied polarizations (first, second, third, and forth polarizations) is orthogonal with respect to each of the other polarizations.

10 15. The method of claim 11 or any one of the above claims,

wherein at least one of the applied codes (17, code 1, code 2, code 3, code 4) is orthogonal with respect to each of the other codes.

16. The apparatus of claim 11 or any one of the above claims, wherein at least one of the modulators (27, 29, 127, 129) is adapted to at least one of the following group
15 comprising:

intensity modulating at least one of the signal parts (16, 6a, 20, 6b, 6c, 6d) to code the signal parts (16, 6a, 20, 6b, 6c, 6d),

using a binary code (code 1, code 2, code 3, code 4) for at least one of the signal parts (16, 6a, 20, 6b, 6c, 6d) to code the signal parts (16, 6a, 20, 6b, 6c, 6d).

20 17. The apparatus of claim 11 or any one of the above claims,

wherein at least one of the correlators (52-1, 52-2, 52-3, 52-4) is adapted to determine the parts of the DUT-signal (32, 140) by multiplying the DUT-signal (32, 140) with each code (code 1, code 2, code 3, code 4).

18. The apparatus of claim 11 or any one of the above claims, further comprising:

25 a first coupler (5) for providing the optical signal (6) to a measurement arm (8) for

using the optical signal (6) as a measurement signal (18) of an interferometer (30), and to a reference arm (12) for providing a reference signal (34), and
a second coupler (35) for superimposing the DUT-signal (32) coming from the DUT (10) with the reference signal (34) of the interferometer (30) before detecting
5 the DUT-signal (32) to provide a resulting superimposed signal (36) to the detector (44, 46).

19. The apparatus of claim 11, further comprising:

a second beam splitter (38) for splitting the resulting superimposed signal (36) into two, preferably orthogonal, parts (40, 42), and
10 a second detector (44) to be able to detect each part (40, 42) separately.

20. The apparatus of claim 11 or any one of the above claims, further comprising:

a delay line (60) in the reference arm (12) for providing the reference signal (34) with a delay ($\Delta\tau$) and with a reference code (code ref), and
a fifth correlator (70) for identifying the reference signal (34) by multiplying the
15 reference signal (34) with the reference code (code ref).

21. The apparatus of claim 11 or any one of the above claims, further comprising:

a fifth modulator (62) prepared to apply the reference code (code ref) to the reference signal (34) which fulfills the following conditions: the product of the reference code (code ref) with the first code (17, code 1) is orthogonal with the
20 product of the reference code (code ref) with the second code (17, code 2), the first code (17, code 1) and the reference code (code ref) are non-orthogonal and the second code (17, code 2) and the reference code (code ref) are non-orthogonal.

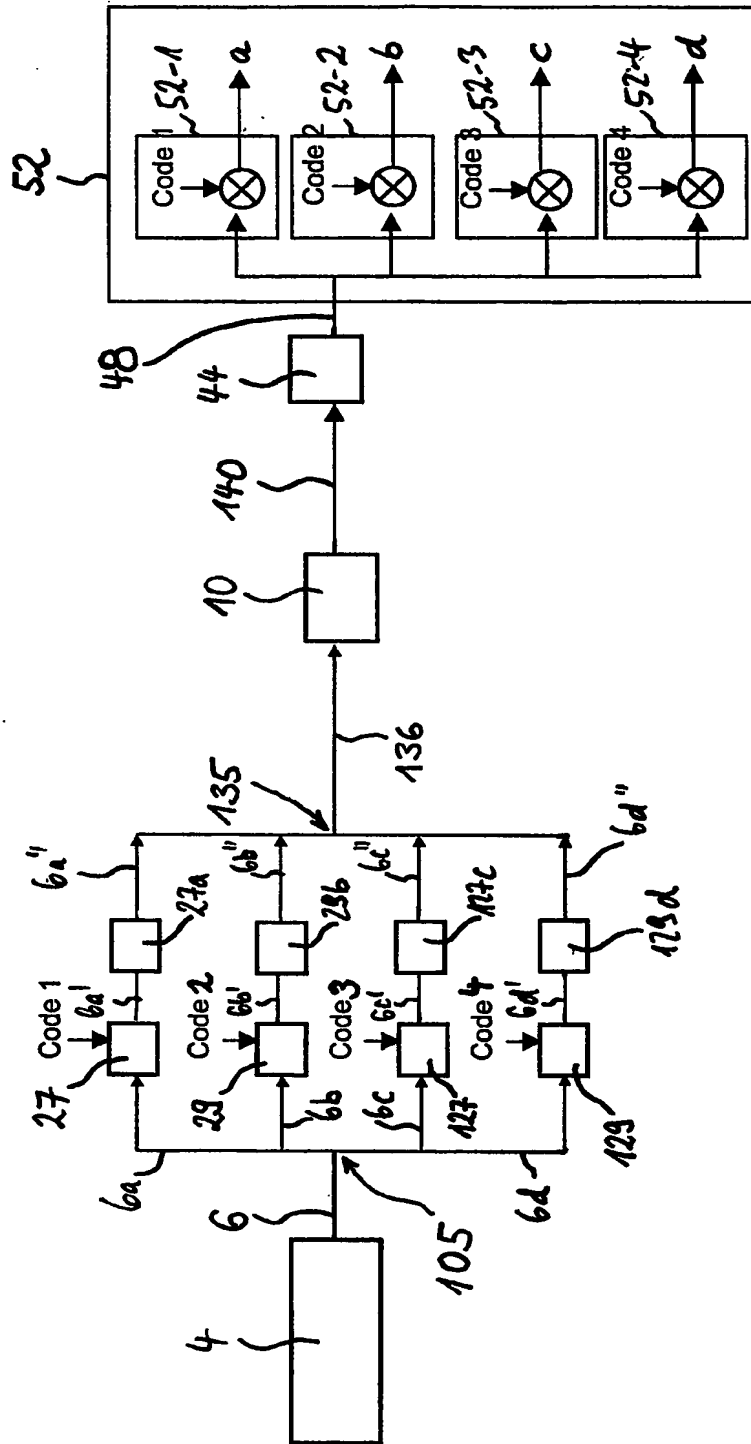


Fig. 1

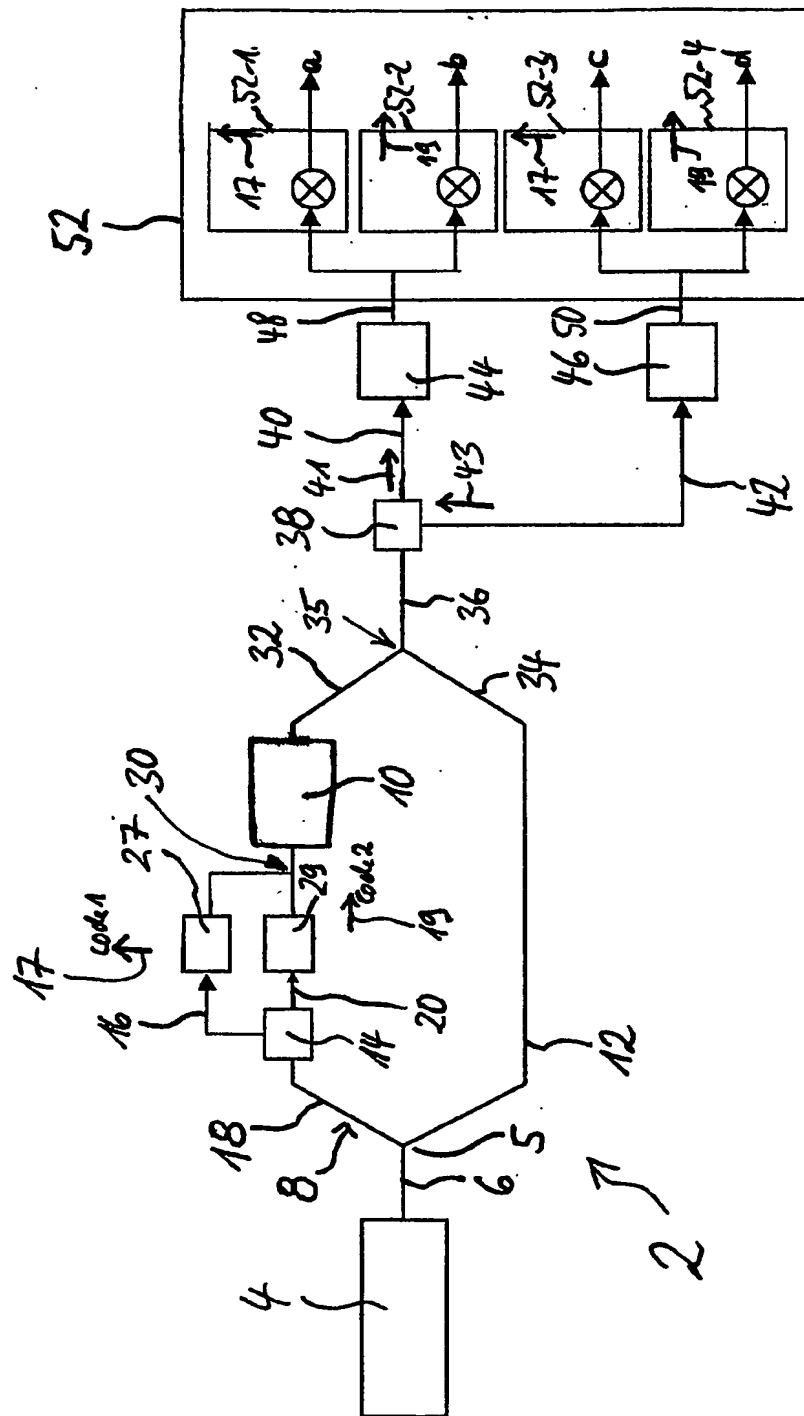


Fig. 2

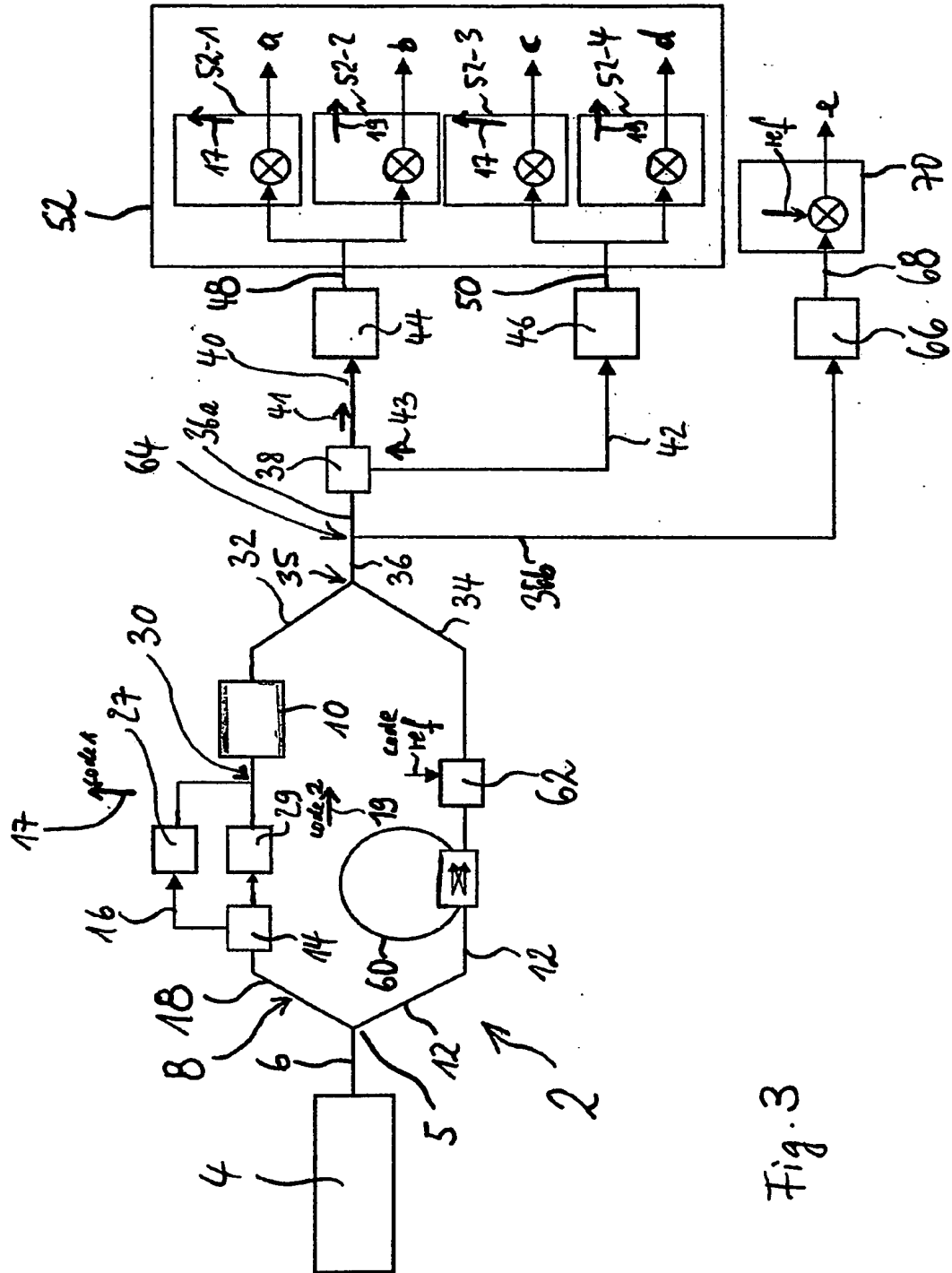


Fig. 3

INTERNATIONAL SEARCH REPORT

national Application No
PCT/EP 02/10285

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B10/08 G01M11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 144 450 A (JOPSON ROBERT MEACHEM ET AL) 7 November 2000 (2000-11-07) column 2, line 62 -column 3, line 10 column 4, line 13 -column 4, line 25 column 5, line 14 -column 5, line 16 column 5, line 38 -column 5, line 49 column 7, line 14 -column 7, line 29 column 8, line 49 -column 8, line 52; claim 46; figure 3	1,3-6, 11,13-16
A	EP 1 113 250 A (AGILENT TECHNOLOGIES INC) 4 July 2001 (2001-07-04) abstract; figure 1	7,8,12, 18,19

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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